

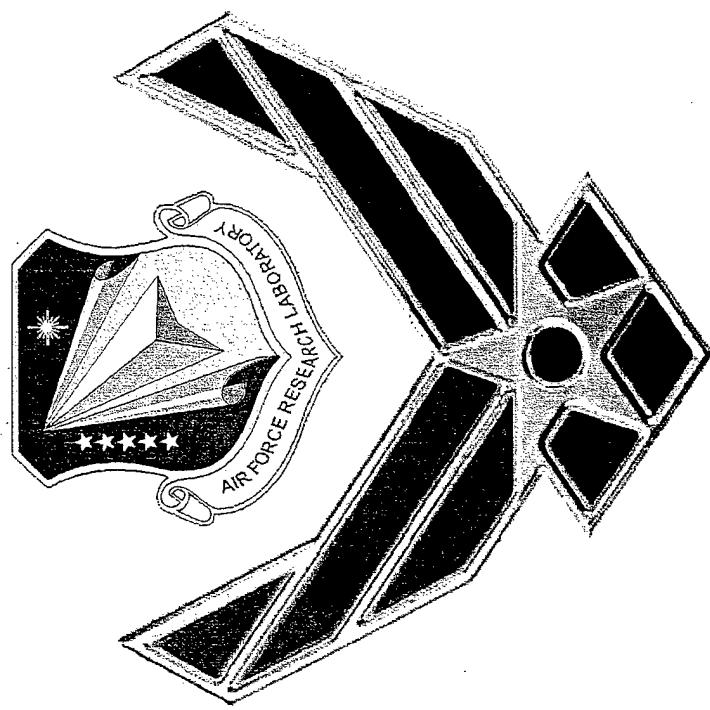
REPORT DOCUMENTATION PAGE

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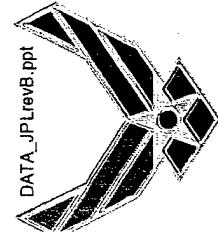
DATA



Joseph Merrell
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Edwards AFB, CA

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That's what it's all about - - -

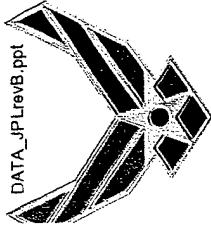
DATA

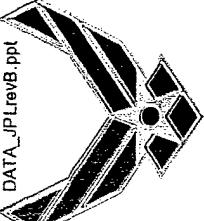
- Data
- Evaluation
- Decision



Objective

- Data Validity
- Data Accuracy
- Data Reliability
- Summarize results



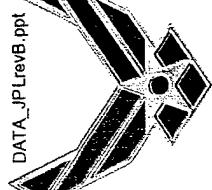


FIRST QUESTION



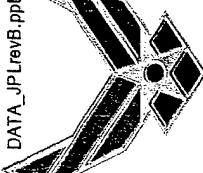
Data Validity: Is the Data Real ?

- Sensor capability
- Sensor installation
- Data system capability
- Do the homework; know expected data range, frequency, and acceptable error
- Need to address OSP environment; thermal cycling, radiation



SENSOR CAPABILITY

- Measurement range
- Frequency response
- Thermal sensitivity/stability
- Zero balance stability
- Vibration sensitivity/stability



SENSOR INSTALLATION

- Connectivity

- Heat
- Tubing

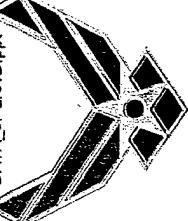
- Orientation

- alignment

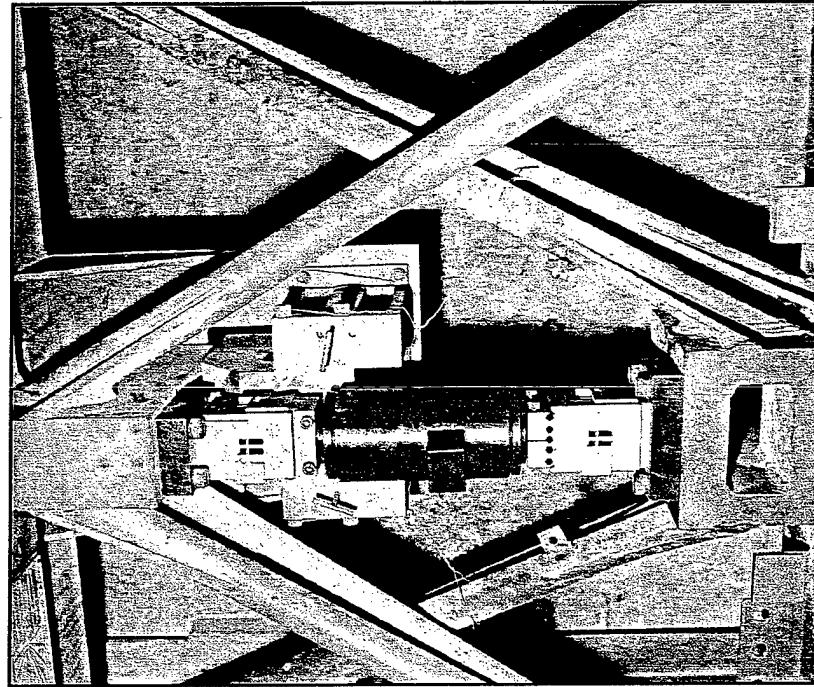
- Excitation

- mV/V

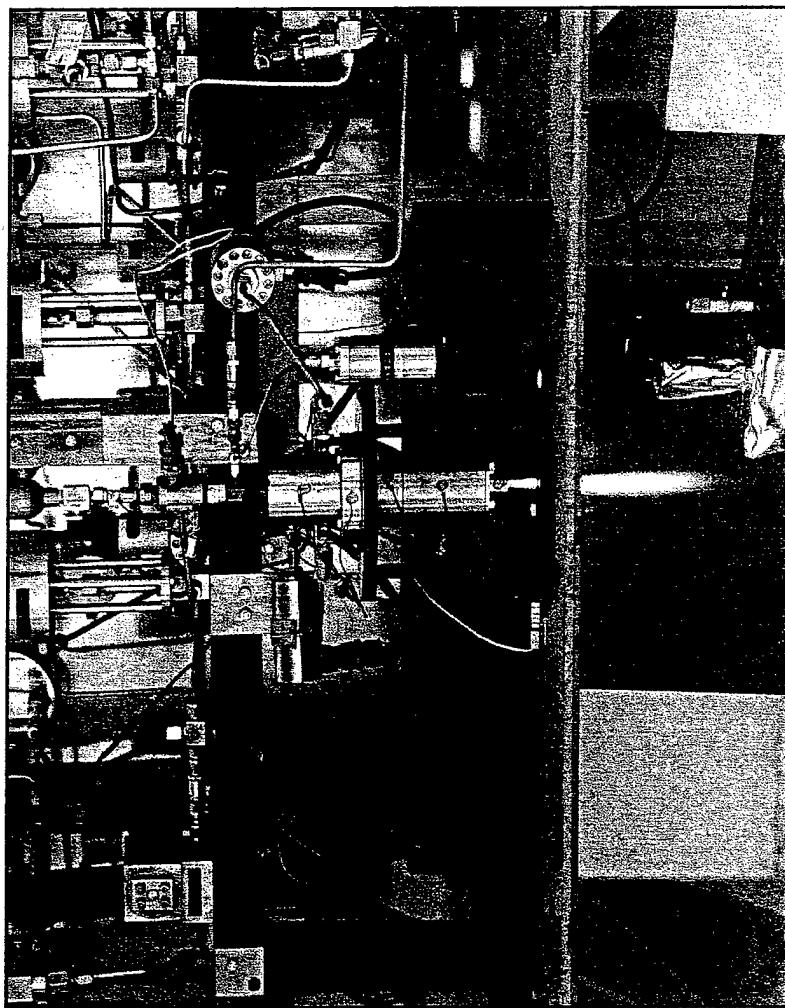
SENSOR INSTALLATION



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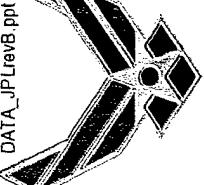
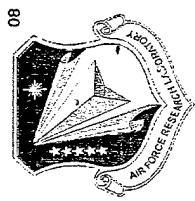


LOAD CELLS



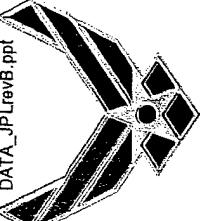
TRANSDUCERS

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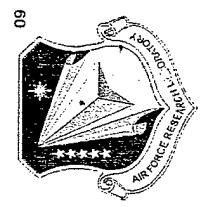


DATA SYSTEM SETUP

- Range
 - Gain/resolution
- Filter
 - Cutoff frequency
- Sample rate
 - Alias



DATA SYSTEM

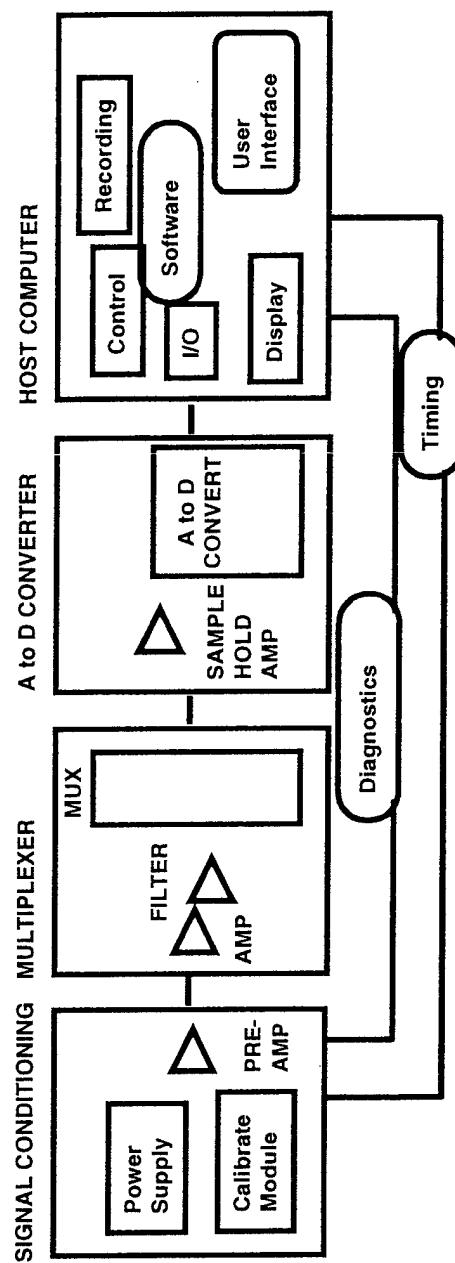


- **System Modules**

- Signal Conditioning
- Multiplexer
- Analog to Digital
- Computer

- **Module Functions**

- Number of Channels
- Throughput
- Data Manipulation
- Precision
- Resolution Accuracy



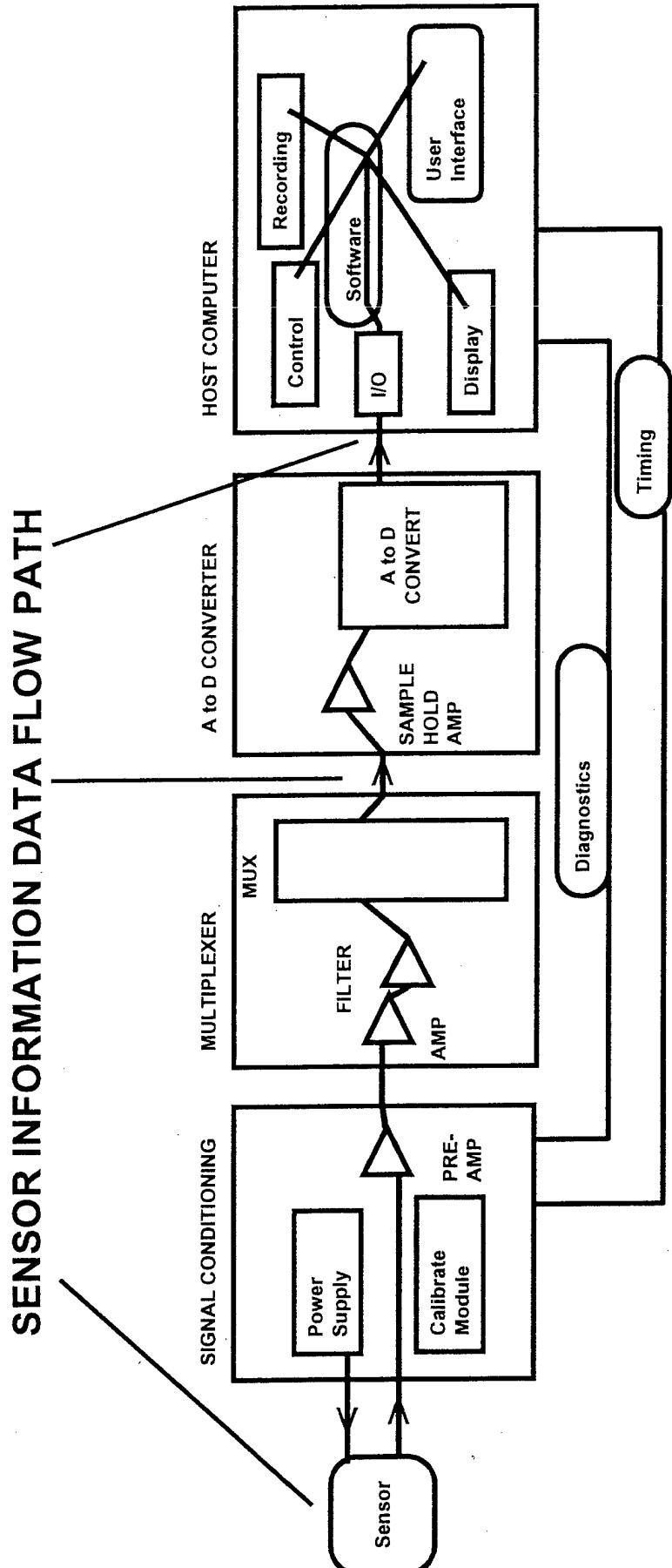
System Capabilities

- Amplification / Attenuation / Resolution
- Signal Sampling / Frequency Response / Anti-Alias
- Aggregate Sampling Rate

DATA FLOW



SENSOR INFORMATION DATA FLOW PATH





DATA VALIDITY



Data Validity: You can know the data is real

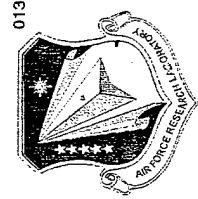
- Do the homework;
 - know the requirements
 - Know the capabilities
- Substantiate the data
 - Noise “non-data” can exist in the data envelope



SECOND QUESTION

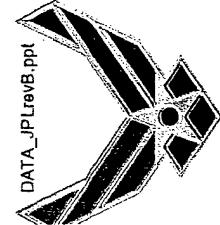
Data accuracy: What is the data error ?

- Do the homework; know expected data range, frequency, and acceptable error
- Does this “acceptable error” include 100%, or 95%, or 68% of the data
- Error components
 - Sensor error +/-
 - Data system error +/-
 - Other error +/-

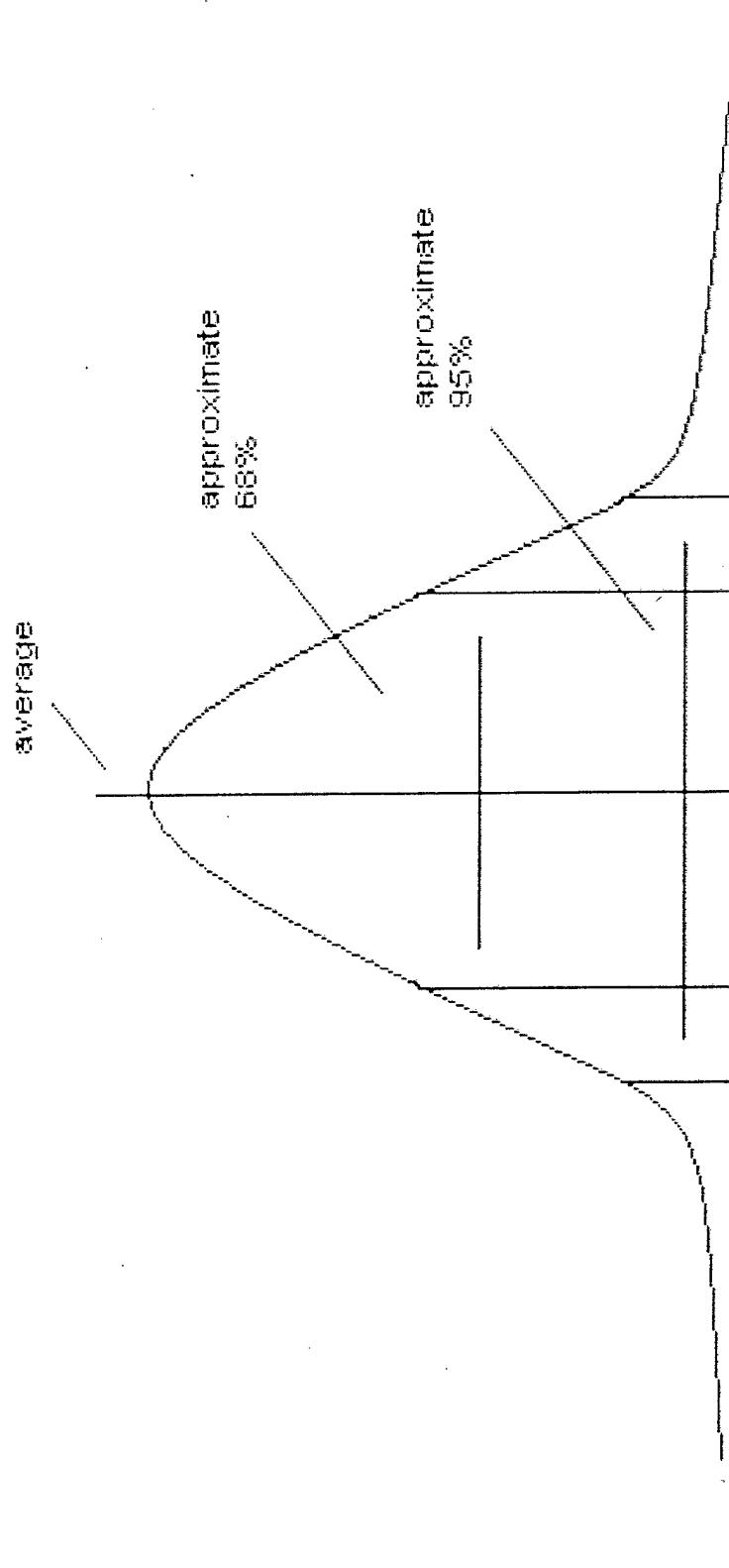


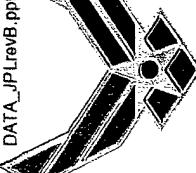
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DATA DISTRIBUTION



Standard data distribution profile

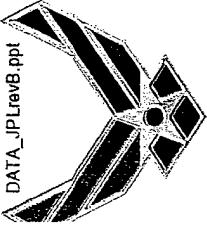




014

DATA ERROR

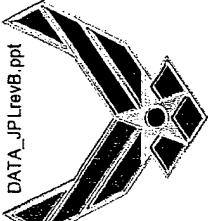
- Example; if a 1500lb pressure sensor reads 700lb
 - The customer will have defined “acceptable error” to be within some range such as;
 - +/- 0.9lb or 0.06%FS
 - +/- 6lb or 0.4%FS
 - +/-19lb or 1.2%FS



SENSOR ERROR

Sensor error may be calculated from manufacturer's specifications sheet

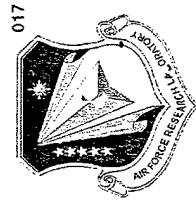
- Bias/offset/zero balance $+/- 1.0\%FS$
- Linearity $+/- 0.2\%FS$
- Hysteresis $+/- 0.2\%FS$
- Repeatability $+/- 0.2\%FS$
- Thermal shift zero $+/- 0.005\%FS$
- Thermal shift span $+/- 0.005\%FS$
- Shock/vibration sensitivity $+/- 0.1\%FS$
- Algebraic sum of error = $+/- 1.71\%$, or $+/- 25.65LB$
- Most conservative
- Root Sum Square (RSS) = $+/- 1.063\%$, or $+/- 15.945lb$
- Less conservative
- Probability that not all error occurs at the same time



SENSOR CALIBRATION

Does this meet data error requirements?

- data requirement; +/- 19lb
- estimated error (RSS approach);
 - +/- 1.063% (1500) = +/- 15.945lb
- Good enough for Decisions?
- Quality/unknowns of specification sheet
 - All sensors / all data
- Large unknown and low confidence level



017

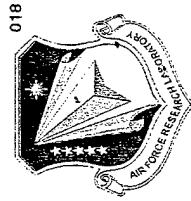
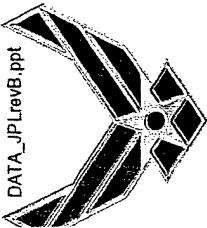
SENSOR CALIBRATION



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Improve sensor error calculation with vendor's calibration.

- Nominally between .15% and .5% FS
- For the 1500lb example this equates to 2.25lb to 7.5lb
- Reduce the 1.06%
- Does this manufacturers "calibration error" include 100%, or 95%, or 68% of the data
- Vendors do not calibrate the same
 - Difficult to correlate sensor data



DATA SYSTEM ERROR

Proved out the manufacturer's specifications, but error back to 1.0% FS

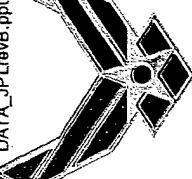
Need to quantify the entire data path error

- Data system error
 - Linearity
 - Zero balance
 - Thermal shift
 - Gain (span)
 - Excitation voltage (value/stability)
 - Common mode
- Other error
 - Cabling; sensor to system (noise, thermal)
 - Random; electro-mechanical (frequency, capacitive induced spikes, etc); Tribo-electric (friction)
 - ?? Barometric, temperature, sun



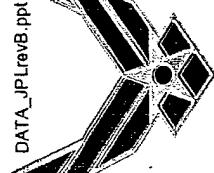
SYSTEM CALIBRATION

- Use in-place system calibration
 - Create a complete data path from sensor to data system
 - Using a known signal “standard”
 - Insert and record multiple steps from 0% through 100% of the sensor range
 - Captures all random error
 - Valid for given point in time
- This curve fit will reduce entire data path error and increase confidence

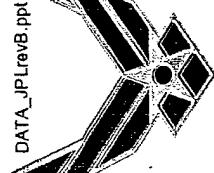


SYSTEM CALIBRATION

- Further reduction of error can be accomplished by using multiple calibrations
- Multiple “in-place” calibrations will capture the variability of all random error
 - Some error is variable
- This curve fit will further reduce entire data path error and increase confidence
 - Capture error variability associated with different points in time



DATA SYSTEM ERROR



DATA SYSTEM ERROR

Sensor calibration by itself

- Reduces error unknown and increases confidence
- Implies that all error is accounted for in the sensor
- Variance is only in data

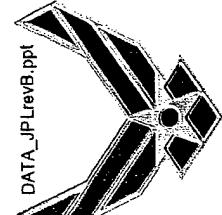
- Disregard of all other error may lead to problems

- Rule of thumb for error of the measurement;

$$\begin{aligned}\text{sensor error} &= \text{approximately } 25\% \\ \text{data system error} &= \text{approximately } 1\% \\ \text{other error} &= \text{approximately } 15\%\end{aligned}$$

- 2 times sensor nominal error from manufacturer's calibration for 1500lb example (.15% to .5%)=
 $2 \times .5\% = +/-1.0\% FS$ (conservative)

$$+/- 1.0\% (1500) = +/-15.0\text{lb}$$
 (conservative)

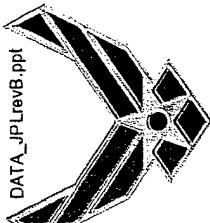


UNCERTAINTY

- Further reduction of error can be accomplished by using uncertainty calculation methods
- Apply standard uncertainty calculations
 - Account for the “sensor calibration” error and the “system calibration standard” error
- Will result in very well defined error band to support decision making
 - High confidence level



THIRD QUESTION



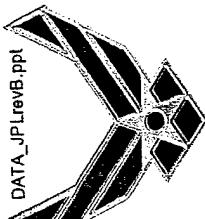
Data reliability: Can the data be trusted?

- Installed sensors may/may not provide trusted data between calibrations
- Any/all of the three error sources may have changed
 - Intermittent signal
 - Zero shift (drift)
- Data deviates from theoretical; higher, lower, or scattered

Data NEEDS to be verified between calibrations



DATA VERIFICATION



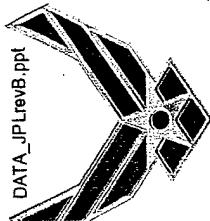
Data verification through VCAL

- Precision voltage insertion provides means to verify a signal “standard” through sensor path
 - Troubleshooting capability for
 - Intermittent signal
 - Zero shift (drift)
 - Data deviation from theoretical; higher, lower, or scattered
- Substantiate any deviation between sensors

Data CAN be verified between calibrations
– System interface cost (added components)



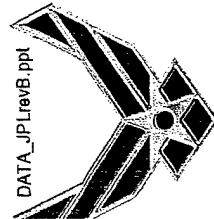
DATA VERIFICATION



Data verification through Smart Sensor

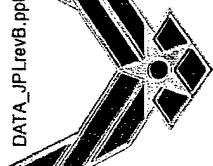
- Computer ship with diagnostic capability integrated into sensor
- Precision voltage/frequency diagnostic signal insertion provides means to verify a signal “standard” through sensor path
 - Troubleshooting capability for
 - Intermittent signal
 - Zero shift (drift)
 - Data deviation from theoretical; higher, lower, or scattered
- Substantiate any deviation between sensors

- Data CAN be verified between calibrations
- System interface cost (sensor weight or added components)



SUMMARY

- Data Validity
- Do homework, know requirements and capabilities
- Data Accuracy
- Calibration allows you to trade a large unknown error for a smaller known error and higher confidence level
- Data Reliability
- Data can be verified



EXAMPLE

Following example shows relationship of error reduction for a 200 lb sensor

- **Manufacture's specifications**
 - Algebraic sum = 1.71% of 200lb = +/-3.42lb
 - RSS = 1.06% of 200lb = +/-2.12lb
 - Only sensor error considered
- **Sensor calibration**
 - Eleven point calibration of 200lb = +/-0.19lb
 - Only sensor error considered
- **System uncertainty**
 - Calibration standard error plus sensor calibration error plus 1500 point system calibration of 200lb = +/-0.21lb
 - All error



EXAMPLE SPECIFICATIONS

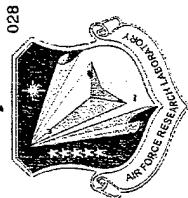
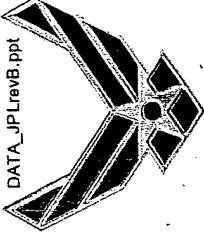
	error	error	sum of squares	RSS	pounds +/-	
200.000	FS	squared				
Linearity	0.2000	0.040000	1.130050	0.0106304	2.1260762	
Hysteresis	0.2000	0.040000				
Repeatability	0.2000	0.040000				
Thermal zero stability	0.0050	0.000025				
Thermal span stability	0.0050	0.000025				
Shock stability	0.1000	0.010000				
Zero balance	1.0000	1.000000				

Following Pages

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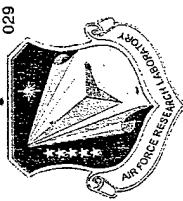
back up

1.



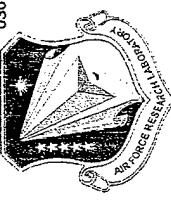
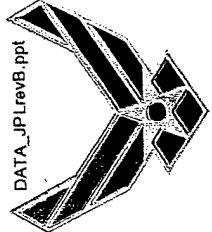
EXAMPLE SPECIFICATIONS

	error	error	sum of	error	pounds +/-
		FS	squared	RSS	
Linearity	0.2000	0.040000	1.130050	0.0106304	2.1260762
Hysteresis	0.2000	0.040000			
Repeatability	0.2000	0.040000			
Thermal zero stability	0.0050	0.000025			
Thermal span stability	0.0050	0.000025			
Shock stability	0.1000	0.010000			
Zero balance	1.0000	1.000000			



EXAMPLE CALIBRATION

MV	Obsr	Predicted	Residual	S.E.E.		T95
				PSIG, Y ₁	PSIG, Y-Y ₁	
-0.006	0	0.0333171	-0.033171	0.033171		
39.970	40	39.979924	0.020076	0.020076		
79.970	80	79.950660	0.049340	0.049340		
119.970	120	119.921395	0.078605	0.078605		
160.090	160	160.012043	-0.012043	0.012043		
200.113	200	200.005762	-0.005762	0.005762		
160.140	160	160.062006	-0.062006	0.062006		
120.070	120	120.021322	-0.021322	0.021322		
80.012	80	79.992629	0.007371	0.007371		
39.970	40	39.979924	0.020076	0.020076		
0.002	0	0.041165	-0.041165	0.041165		



EXAMPLE UNCERTAINTY

Systematic value sensor calibration

$Br = \text{systematic}/2 =$

$Br_a^2 =$

Systematic value data calibrator

$Br_b^2 =$

$Sx_{\text{pooled}} = \{\sum [(v_i)(Sx_i^2)/v_i]\}^{1/2}$

$Sx_{\text{pooled}} =$

$Sx_{\bar{}} = Sx / \sqrt{N} = S_{\bar{x}}$

$S_{\bar{x}} = Sx_{\bar{}} =$

$S_{\bar{x}}^2 =$

$U95 = +/- t_{95} [\sum ((Br_a^2) + (Br_b^2) + (S_{\bar{x}}^2))^{1/2}] =$

$\text{Bandwidth} = 2 \times U95 =$

All S x squared

0.19202 psig

0.09601 psig

0.00922 psig

2.5E-05 psig

0.208185041

0.764624832

4.723064697

14.25787016

22.22120356

12.20733573

2.1502879

total all N-1s

2626

0.00176 psig

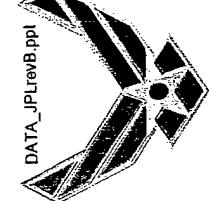
percent step

0.2098 psig

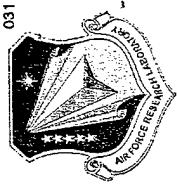
total all Sx * N-1

12141.93654

0.4196 psig

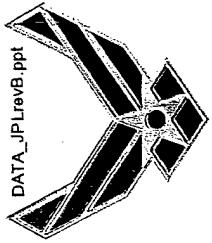
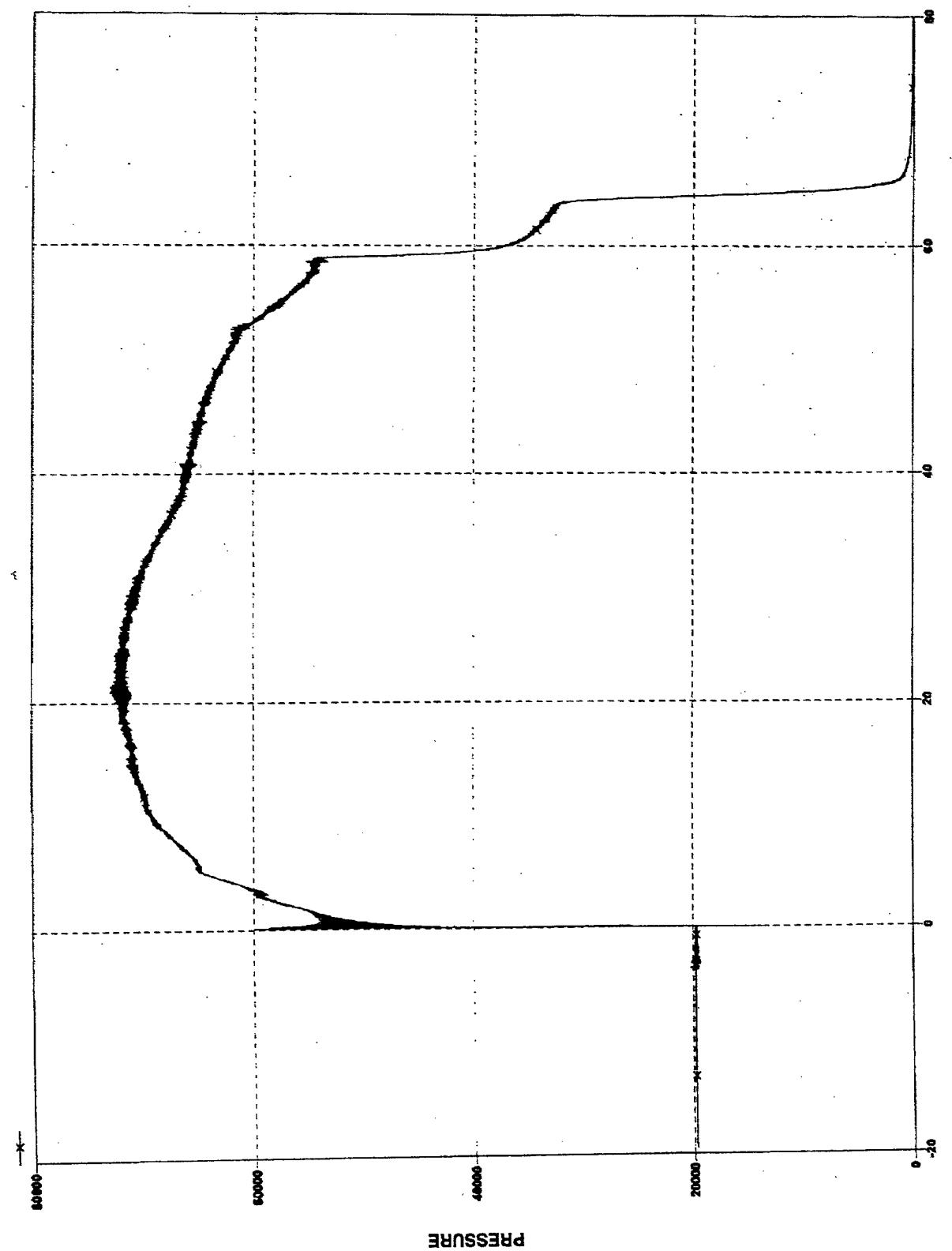


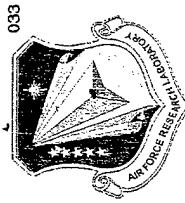
UNCERTAINTY



$$\bullet U_{95} = +/- t_{95} \sqrt{(B_r/t)^2 + (S_r^2)}$$

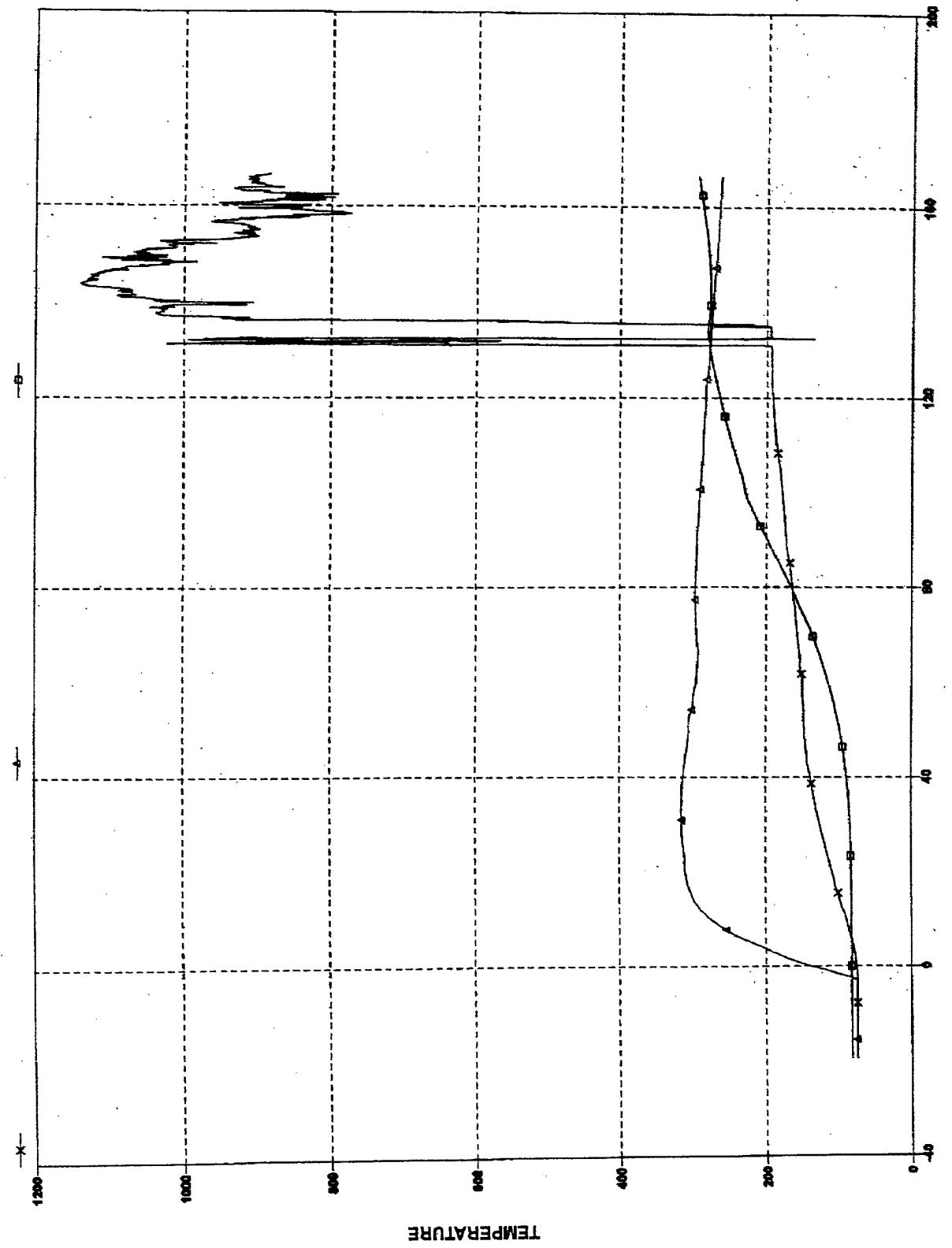
- t_{95} (Student's t); statistical value table for 95% confidence
 - Where v (number of samples minus 1) is greater than or equal to 30
- t ; statistical value where B_r is not a 95% confidence number
 - $t = 2$ when v is greater than or equal to 30
- B_r (systematic error)
- Known signal standard
- Sensor calibration/curve fit
- S_r (random)
- Current multiple data steps recorded through the sensor

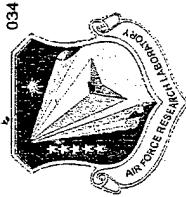




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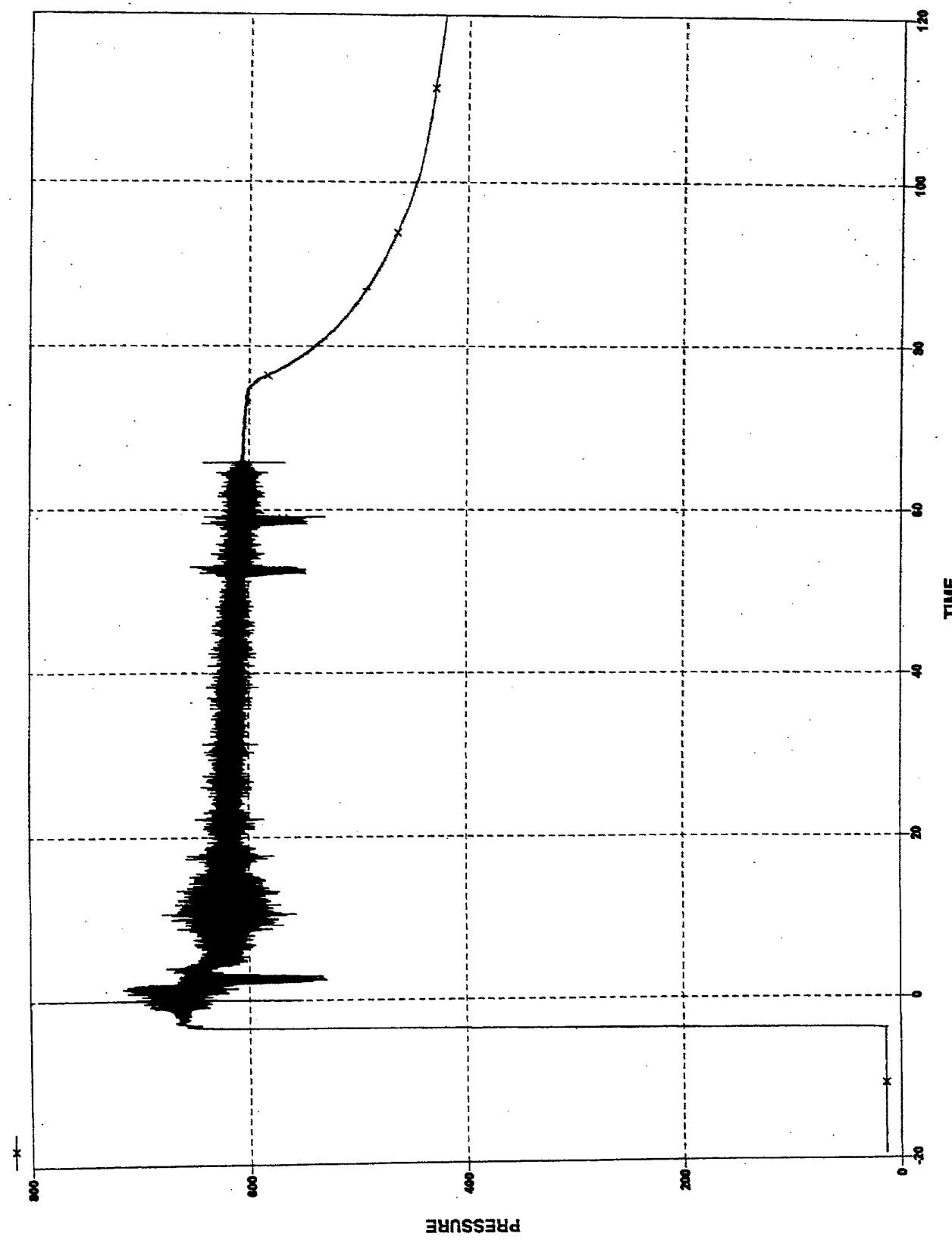




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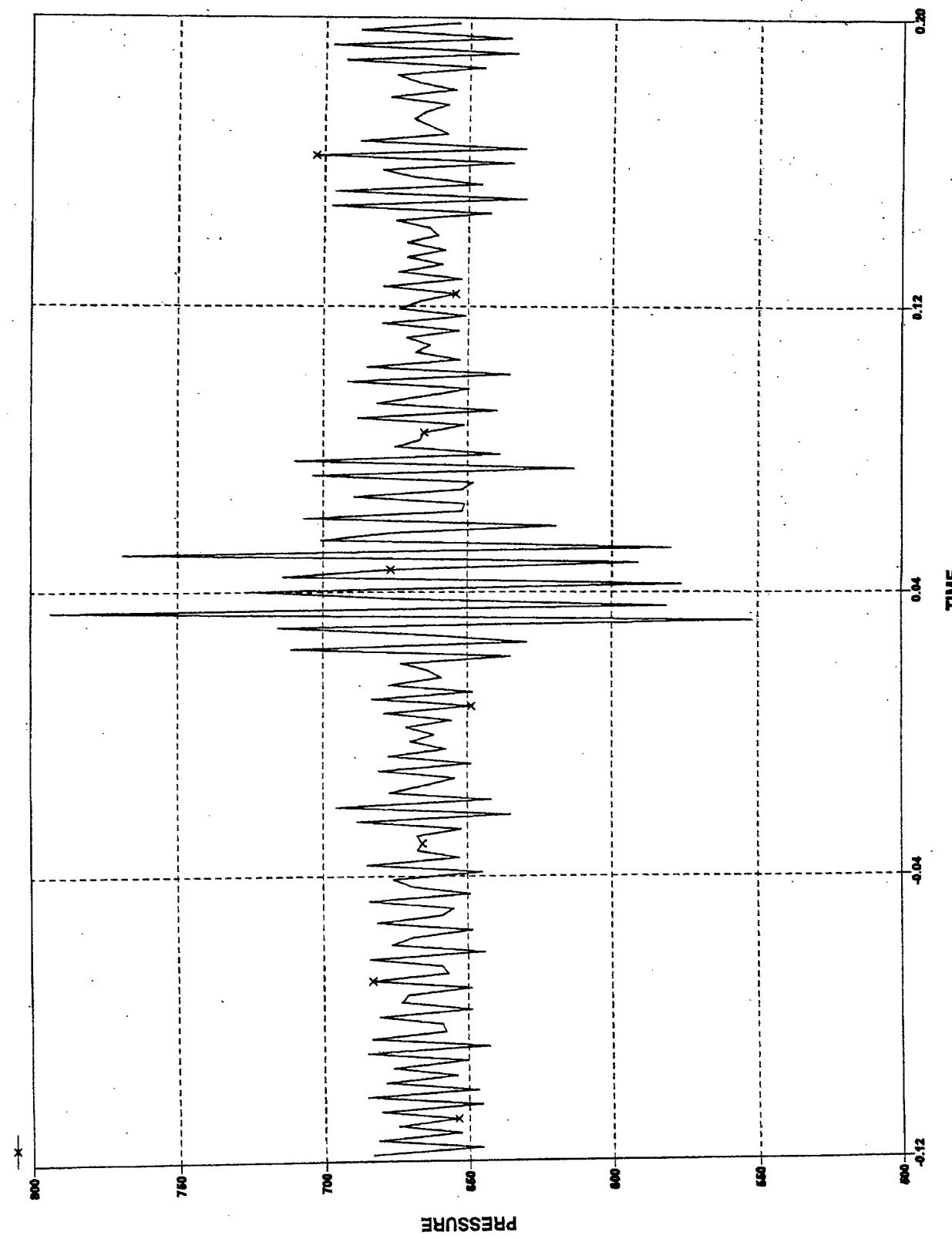




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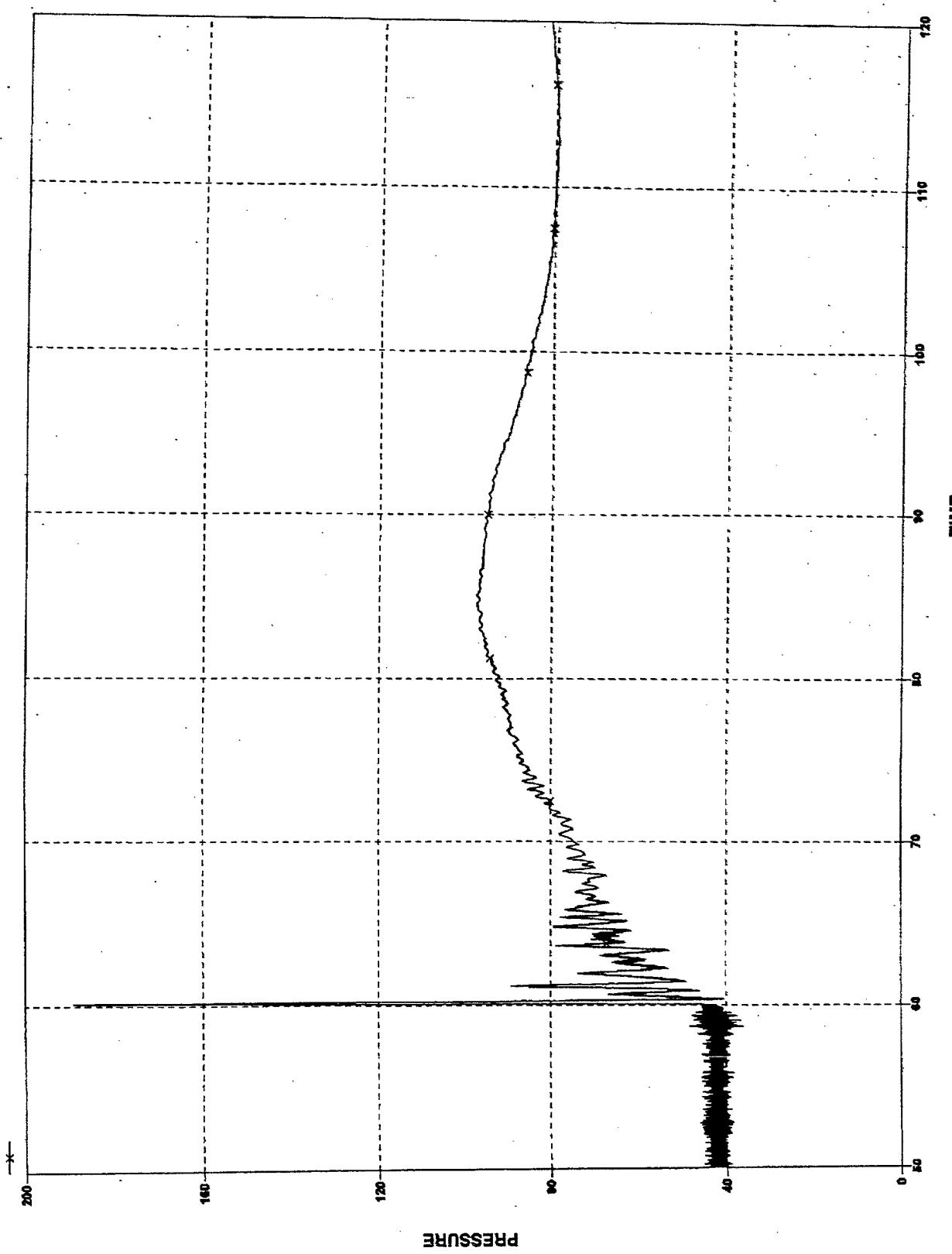
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DATA_JPLrevB.ppt

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